

Rings, rings, rings: what does CN tell us?

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Abstract. CN emission lines are among the brightest, and have been observed in the last 20 years with single dish observations. With modern interferometers, we are now able to spatially resolve CN emission, which often shows ring-like structures. We investigate whether such structures trace the morphology of the disks, or if they have a chemical origin. By using the thermochemical code DALI, we conclude that CN formation is triggered by the existence of vibrationally excited H_2^* , produced by FUV pumping of H_2 . Herbig stars therefore generally have larger rings and higher CN fluxes than T Tauri. Disks with higher masses and flaring also show stronger CN emission and larger rings. CN observations could in the future provide important constraints on some important disk physical parameters. The results of the models are well consistent with the spatially resolved CN observations to-date available.

Keywords. astrochemistry – planetary systems: protoplanetary disks – methods: numerical – radiative transfer

1. Motivation

CN is one of the brightest molecules that have been observed in protoplanetary disks, and its lines can be as bright as those of ^{13}CO or even brighter. For this reason CN has been observed and studied both with single-dish (Thi *et al.* 2004; Kastner *et al.* 2008, 2014; Salter *et al.* 2011; Guilloteau *et al.* 2016) and interferometric observations (Dutrey *et al.* 1997; Öberg *et al.* 2010, 2011; Chapillon *et al.* 2012; Guilloteau *et al.* 2014)

However, only in recent years have spatially resolved observations of CN become available (Teague *et al.* 2016; van Terwisga *et al.* in prep.), showing ring shaped emission. The well studied disk around TW Hya, for example, shows a ring located at a radius of 47 AU from the star (Fig. 1), and the same is evident in two disks in the Lupus young star-forming region, namely Sz 78 and Sz 91.

We investigate whether such rings are due to the global morphology of the disks (e.g. transitional disks), or if they can originate from chemical processes depleting the inner disk of CN even in full disks. We also study which stellar and physical disk parameters mostly affect CN emission in order to understand what information can CN observation provide about protoplanetary systems.

2. Methods

We run a grid of full disk models using the thermochemical code DALI (Bruderer 2013) to self-consistently solve for the abundance of molecular species and the thermal balance of the gas. A chemical network accounting for the most relevant nitrogen chemistry reactions is adopted (Visser *et al.* in prep., this volume). The total mass of the disks M_{tot} is varied between 10^{-5} and $10^{-1} M_{\odot}$, the flaring of the disk ψ between 0.1 and 0.3, and the disk aspect-ratio between 0.1 and 0.2. Two different stellar spectra are adopted,

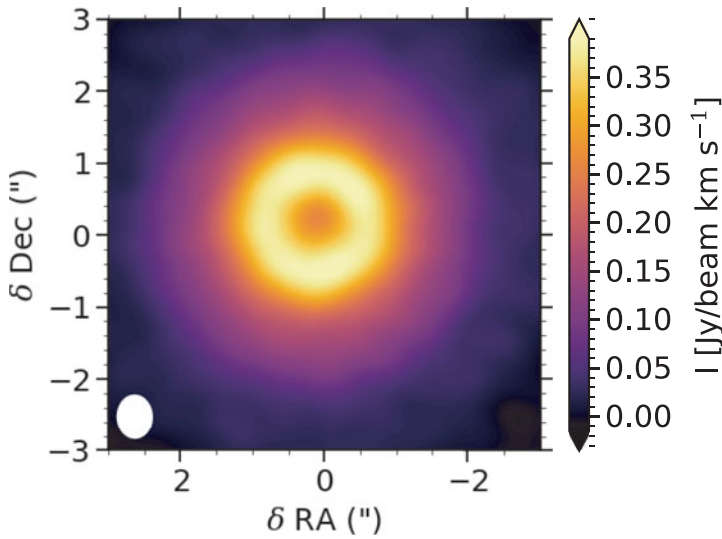


Figure 1. The CN ($N = 2 - 1$), $0.9''$ (47 AU) radius ring observed with ALMA in TW Hya (data from Teague *et al.* 2016).

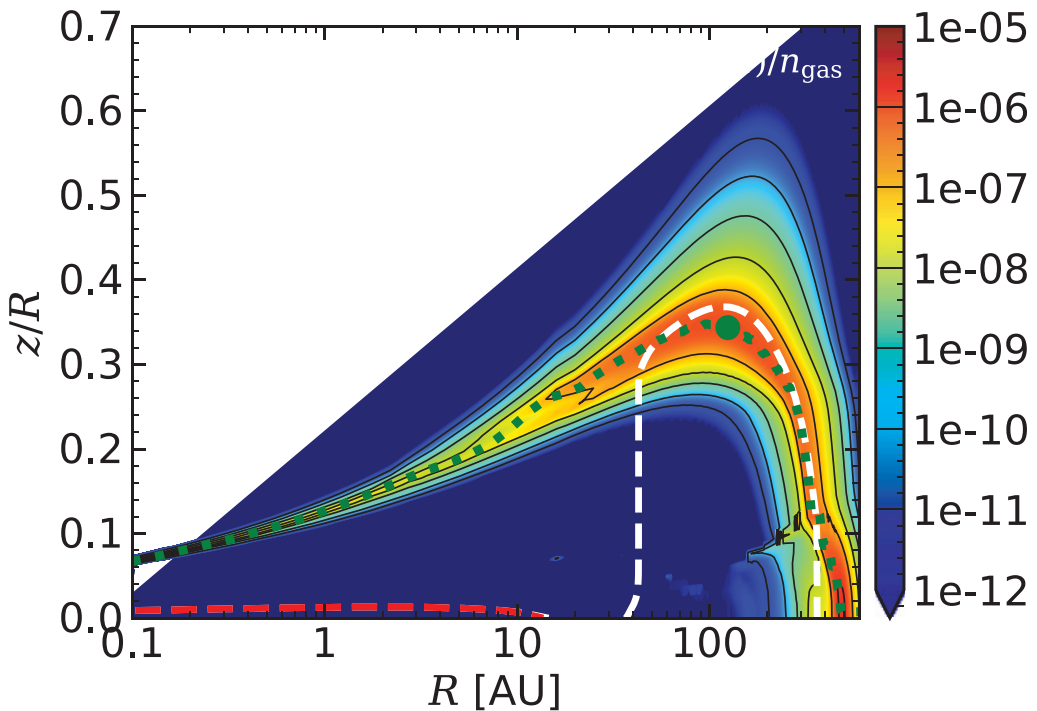


Figure 2. Abundance of CN in a representative disk around a T Tauri star. The green dot marks the location of the maximum, while the dotted green line marks the location of the vertical CN abundance maximum at each radius. The white dashed line marks the $\tau = 1$ layer of the CN ($N = 3 - 2$) line. Similarly, the red dashed line shows the $\tau = 1$ layer at the same wavelength for the dust. Such a profile is consistent with the observed ring-shaped emission. Adapted from Cazzoletti *et al.* (in press)

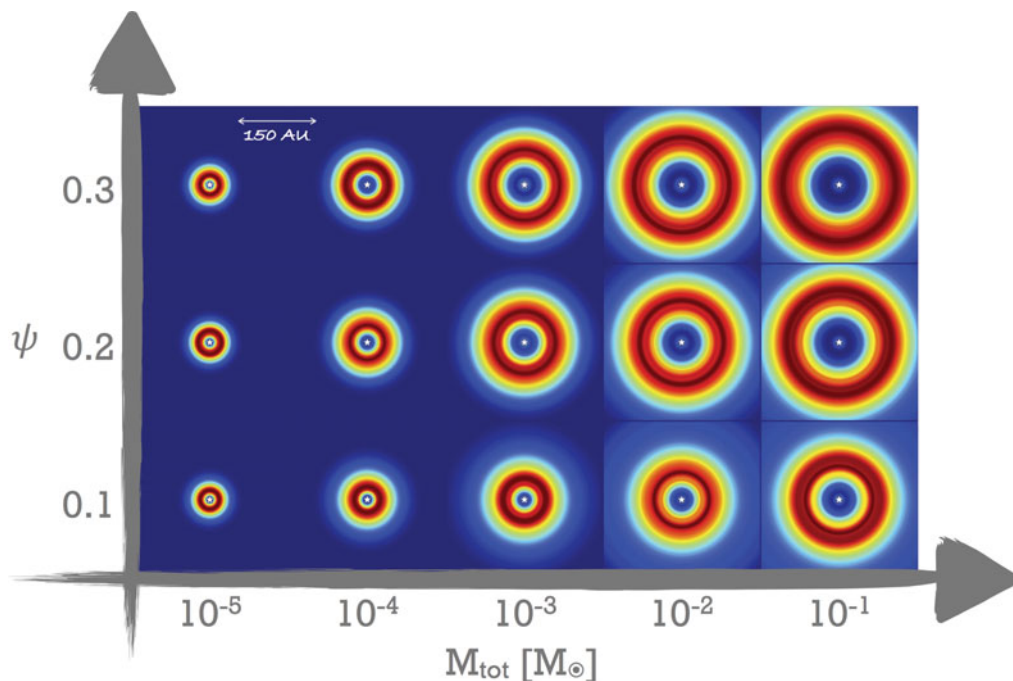


Figure 3. Model images of the CN (N,J)=(3-2, 7/2-5/2) transition emission from full disks around Herbig stars (normalized to peak). Higher masses and flaring show larger rings and higher fluxes. T Tauri stars show similar trends, with smaller rings.

representing a Herbig star and a T Tauri star with a UV excess due to a $10^{-8} M_{\odot} \text{year}^{-1}$ accretion rate ($L_{\text{UV}} = 1.5 \times 10^{-4} L_{\odot}$).

3. Results

The CN abundance distribution is qualitatively similar for all of our models: CN is most abundant in the upper layers of the outer disk, and is less abundant in the inner disk (Fig. 2). Such a distribution naturally translates into a radial column density distribution peaking between a few tens and ~ 200 AU, consistent with the observed ring-shaped emission. Indeed, ring-shaped emission is observed in all of our models, and the following additional results and trends are identified:

- T Tauri disks generally show smaller rings than Herbig disks
- CN fluxes in Herbig and T Tauri disks are comparable, ranging between $\sim 1 \text{ Jy km s}^{-1}$ and $> 10 \text{ Jy km s}^{-1}$
- The size of the rings increases with the mass and the flaring of the disks (Fig. 3). These trends are observed in both Herbig and T Tauri disks.
- CN emission is mostly optically thin, and the integrated flux increases with M_{tot} . However, this dependence weakens for the most massive disks, where the emission becomes marginally optically thick.
- CN is not strongly affected by the overall abundance of volatile C and O, and even depleting these species up to a factor of 100 causes the CN flux only to vary by a factor of 2.
- The main formation route of CN is triggered by vibrationally excited H_2^* reacting with N to form NH, which in turn reacts with C and C^+ to form CN. This is evident

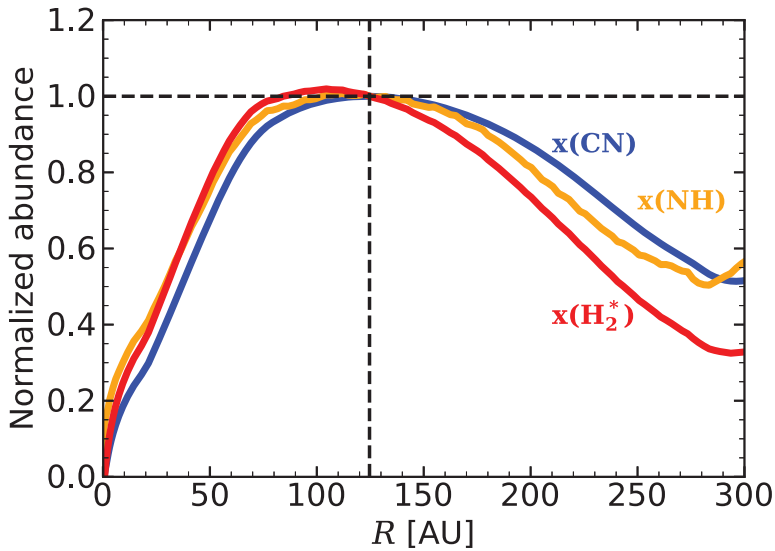


Figure 4. Abundance profile of H_2^* , NH and CN, calculated along the dotted green line in Fig. 2, and normalized at their value at the location of the CN abundance maximum (green dot in Fig. 2). The three species show very similar distributions. Adapted from Cazzoletti *et al.* (in press).

by comparing the abundance distributions of H_2^* , NH and CN (Fig. 4): all three species peak at the same radius.

CN measurements of flux and ring size can therefore be used to put constraints on some disk parameters such as the local UV flux, the flaring of the disks at large radii, and even the size of the disk. For a more details on the modelling and the results, we refer the reader to Cazzoletti *et al.* (in press).

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